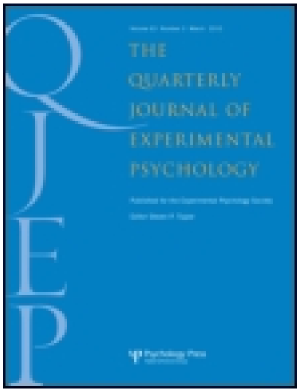

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Motor simulation in verbal knowledge acquisition

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Short article

Motor simulation in verbal knowledge acquisition

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Recent research highlights the importance of motor processes for a wide range of cognitive functions such as object perception and language comprehension. It is unclear, however, whether the involvement of the motor system goes beyond the processing of information that is gathered through active action experiences and affects also the representation of knowledge acquired through verbal learning. We tested this prediction by varying the presence of motor interference (i.e., squeezing a ball vs. oddball detection task) while participants verbally acquired functional object knowledge and examined the effects on a subsequent object detection task. Results revealed that learning of functional object knowledge was only impaired when participants performed an effector-specific motor task while training. The present finding of an effector-specific motor interference effect on object learning demonstrates the crucial role of the motor system in the acquisition of novel object knowledge and provides support for an embodied account to perception and cognition.

Keywords: Embodied cognition; Tool use; Semantic learning; Object perception; Implicit memory.

Imagine yourself ambling through an archaeological museum and observing the exhibits of objects from the ancient empires. Some of the tools used in these times seem very unfamiliar to you. Fortunately, although you will never experience their function through your own actions, you can make sense of these objects through reading the explanations on the information panel. As this example illustrates, knowledge about the functional use of objects can be acquired even without handling an object. But how do we acquire functional object knowledge that is not based on direct sensorimotor experiences?

Developmental research has accumulated evidence demonstrating that action knowledge about tools is acquired through motor experiences (Barrett, Davis, & Needham, 2007) or the observations of others' actions (Elsner & Pauen, 2007). These two learning mechanisms indicate that functional object knowledge goes beyond a direct association between visual object features and afforded actions (Tucker & Ellis, 1998; cf. Gibson, 1979). In the same vein, recent studies demonstrate that participants are slower to identify an object depicted in a position that deviates from its actual correct use than an object depicted

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in a position that is appropriate with respect to the experienced function (van Elk, Paulus, Pfeiffer, van Schie, & Bekkering, 2009; van Elk, van Schie, & Bekkering, 2008). However, it has been recently argued that object knowledge relies also on language-related representations and semantic information processes (e.g., Creem & Proffitt, 2001). Evidence for this notion comes from behavioural (Lindemann, Stenneken, van Schie, & Bekkering, 2006) and neuroimaging studies (Canessa et al., 2008) showing that semantic information concerning the use of objects is activated during the performance and observation of object-related actions. For example, Creem and Proffitt (2001) reported that participants grasped familiar household tools more frequently inappropriately with respect to their function when the motor task was paired with a concurrent semantic task but not when it was paired with a visuospatial task suggesting that semantic processing is required when grasping a tool appropriately for its use.

Several theorists in the field of cognitive psychology have proposed that knowledge about actions and objects is bodily grounded in sensorimotor experiences (for reviews, see Barsalou, 2008; Fischer & Zwaan, 2008). Following these so-called embodied cognition approaches, it is assumed that the processing of knowledge of functional objects consists in a covert simulation of associated motor programmes and a reenactment of the objects' functional use. Accordingly, neuroimaging studies have shown an activation of motor areas during observation of tools (e.g., Chao & Martin, 2000). Furthermore, evidence has been provided that this motor activation during passive observation of objects is based on one's own action experiences with these objects (Kiefer, Sim, Liebich, Hauk, & Tanaka, 2007). However, as illustrated by the museum anecdote above, people can acquire functional knowledge about an object without having any actual motor experiences with that object. According to the view of embodied cognition, also such verbally acquired action knowledge should be based on mental simulations of the actual object use.

The present study aimed to test this prediction derived from the embodied cognition account and investigated whether the verbal acquisition of functional object knowledge involves simulation within the motor system. To do so, we manipulated the presence of motor interference (i.e., an alternating squeezing of soft balls with the hands; Witt & Proffitt, 2008) while participants verbally learned the functions of unknown objects (i.e., through sentences describing the object function). If motor simulation mediates the acquisition of object knowledge, it can be expected that learning performances are impaired for participants performing a secondary motor task as compared to participants conducting a task without motor demands or no secondary task. In other words, we hypothesized that a simultaneously performed motor task affects the participants' capability to simulate the motor action associated with the object, which should in turn result in an impaired acquisition of functional object knowledge. Since neuroimaging studies of language processing have shown a somatotopically organized pattern of activation in premotor cortex for words denoting actions that are related to different body parts (e.g., Hauk, Johnsrunde, & Pulvermüller, 2004; Rueschemeyer, Brass, & Friederici, 2007), one might speculate that motor simulation while verbal learning is also effector-specific in nature. To investigate whether the acquisition of manual functional object knowledge is differently affected by a motor interference of another effector than the hand, we introduced an additional condition, in which participants performed as a dual task alternating movements with the feet. To test the functional object knowledge acquired in the learning phase, we used an object-detecting task that has been shown to be sensitive to functional object knowledge (van Elk et al., 2008) and contextual action cues (Fischer, Prinz, & Lotz, 2008).

Method

Participants

A total of 64 students of the Radboud University Nijmegen (19–39 years) participated in the experiment in return for 8 euros or course credits.

Set-up and stimuli

Four novel objects without a predefined function were constructed (see Figure 1A) and divided into two object sets. Each object set consisted of one object that was associated with the action *smelling* (smell-object) and one that was associated with the action *hearing* (hear-object) so that both actions were represented in each object set. Photographs of the objects served as stimuli in the training phase (object picture) and as primes in the object recognition task of the test phase. As target stimuli for the object recognition task, we used photographs of a person using or holding the objects in different way (action pictures; see Figure 1B). In order to reduce stimulus–response automaticity, we used two different action pictures for each object use. To be precise, for each object four different action pictures were taken, in which the correctness of the object use was systematically varied. Two action pictures showed a particular object used correctly with respect to the previously learned function (correct action; e.g., smell-object at the nose). The other two pictures depicted an incorrect object use (incorrect action; e.g., smell-object at the cheek). Just as the correct action of every object had a specific position on the person's face (e.g., hear-object at ear), the incorrect action of every object also had a specific position, which was different for each object and never involved the nose or the ears. All photographs sustained a viewing distance of 80 cm and a visual angle of 13 × 13 degrees.

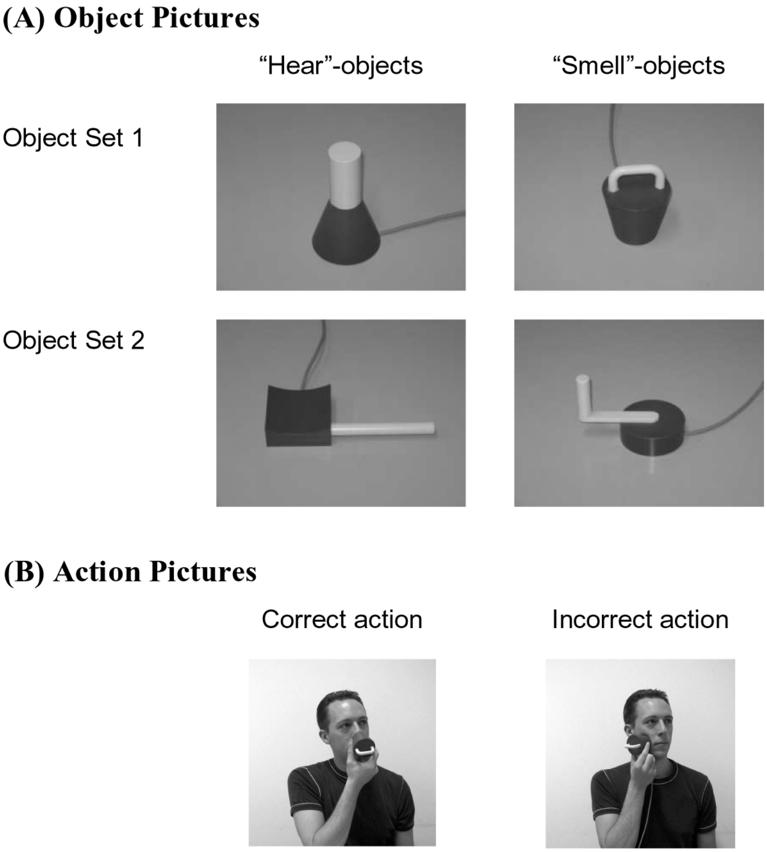

Figure 1. *Part A shows the object pictures used in the experiment. Part B gives an example of the action pictures used in the experiment. In the example the "smell"-object of Object Set 1 is presented at a correct and an incorrect position regarding the function of the object.*

Procedure

Training phase. Participants were indicated to learn verbally the functional use of one hear-object and one smell-object (trained objects). No function was associated with the remaining two objects (untrained objects). At the beginning of each trial, participants pressed a button. Afterwards a fixation cross was presented for 500 ms, followed by an object picture. If the depicted object was functional, participants were instructed to release the button and repeat a standardized sentence describing the function of the object ("With this object you can smell [hear] something"). If the depicted object was not associated with a functional use, no response was required, and the next trial was initiated after 3 seconds. The object picture disappeared after participants finished the sentence and pressed again the button to initiate the next trial.

Importantly, participants were randomly assigned to four different training conditions. In each condition participants performed the verbal learning task. In the *no interference* condition, participants merely placed their hands in front of the button box. In the *hand interference* condition, participants performed a hand-related motor task during sentence articulation. Specifically, they were instructed to grasp with each hand a squeezable foam rubber ball, hold the forearms upwards, and squeeze the foam balls alternately in the right and left hand during sentence articulation. In the *foot interference* condition participants performed foot movements as a dual motor task and squeezed, analogous to the hand interference condition, alternately two rubber balls that were placed underneath their feet. In the *attentional interference* condition, participants performed simultaneously an auditory oddball target detection task. That is, during the whole training session beep tones (1,500 Hz lasting for 5 ms) were presented alternating at the left and right side. With a likelihood of 10% the frequency and duration deviated from the other sounds (i.e., oddball target; 440 Hz lasting for 250 ms). Participants had to remember the location of the last oddball target, because they were occasionally asked to indicate this by a left/right keypress response.

Test phase. The test phase comprised an object recognition task similar to the task used by van Elk et al. (2008). Each trial started with a fixation cross for 500 ms, followed by a 1,000 ms presentation of an object picture. Another fixation cross appeared for 1,000 ms and was followed by a picture of a person using the object. Participants were required to signal as fast as possible whether the object in the action picture was the same as that presented in the first picture or not. The matching of the object and action pictures was indicated by a left/right button press response. The picture disappeared, and the next trial started immediately after the response was finished.

Design

The four different training conditions (no interference, hand interference, attentional interference, foot interference) were randomly assigned to the participants. To prevent participants from getting familiarized with the pictures depicting the incorrect use of the object during the test phase, three training and test phases were presented in an alternating fashion. During each training phase, each object picture was presented 12 times, resulting in 24 trials with and 24 trials without sentence articulation. Each test phase comprised 96 target trials consisting of the four objects (two trained, two untrained) each used in two different ways (twice in a correct way and twice in an incorrect way). In these target trials the object in the action picture was the same as that presented in the first picture, and a "yes"-response was required. Additionally 48 catch-trials were included where the object in the action picture was different from the object in the first picture, and a "no"-response was required. The training of the two different object sets was counterbalanced between participants.

Data analysis

Reaction times (RTs) were measured relative to onset of the action picture. Trials with incorrect responses, trials with RTs deviating more than two standard deviations from the mean RT, and the first three trials of the first block (practice trials) were excluded from the subsequent analyses. Trained and untrained

Table 1. *Mean reaction times and standard errors to identify trained and untrained objects as a function of the different training conditions and the correctness of the depicted actions*

	Trained object		*Untrained objects*	
Training condition	*Correct action*	*Incorrect action*	*Correct action*	*Incorrect action*
No interference	510 (19)	565 (19)	561 (18)	571 (18)
Hand interference	504 (16)	515 (13)	538 (14)	536 (13)
Attentional interference	530 (28)	569 (29)	569 (29)	566 (27)
Foot interference	458 (15)	492 (14)	490 (17)	497 (16)

Note: Reaction times in ms; standard errors in parentheses.

objects were analysed separately using a two-way analysis of variance (ANOVA) with the within-subjects factor object use (correct, incorrect) and the between-subjects factor training condition (no interference, hand interference, attentional interference, foot interference).

Results

Participants incorrectly responded to action pictures in less than 1% of the trials. No difference was found in the error rates between the four training conditions ($F < 1$).

The RT analysis for the untrained objects revealed only a main effect of training condition, $F(3,\ 60) = 3.15$, $p < .05$, $\eta_p^2 = 0.17$. Post hoc comparisons revealed that participants in the foot interference condition performed faster than participants in the no interference and the attentional interference condition, both ps $< .01$.

The ANOVA for trained objects revealed a main effect of object use, $F(1,\ 60) = 44.15$, $p < .001$, $\eta_p^2 = 0.42$, reflecting faster responses to pictures depicting an correct object use (514 ms) than to those depicting an incorrect object use (550 ms). Also the factor training condition reached significance, $F(3,\ 60) = 2.96$, $p < .05$, $\eta_p^2 = 0.13$. Post hoc comparisons revealed faster responses in the foot interference (475 ms) condition than in the no interference condition (538 ms), $t(30) = -2.81$, $p < .01$, and the attentional interference condition (549 ms), $t(30) = -2.37$, $p < .05$. Most importantly, the object use effect was modulated by the different training conditions as indicated by an significant interaction between the factors object use and training condition, $F(3,\ 60) = 3.11$, $p < .05$, $\eta_p^2 = 0.14$ (see Table 1).

To explore the observed interaction in greater detail, we computed for each participant the learning effect defined as average RT difference between trials with correct and incorrect object use (see Figure 2). Interestingly, we observed substantial learning effects for the conditions no interference, one-sample $t(15) = 3.81$, $p < .01$, attentional interference, one-sample $t(15) = 3.46$, $p < .01$, and foot interference, one-sample $t(15) = 4.29$, $p < .01$. However, there was no learning effect for the hand interference condition, one-sample $t(15) = 1.83$, $p > .09$. Pairwise t tests revealed furthermore that average RT difference in the condition hand interference (11 ms) was significantly smaller than that in the conditions no interference (56 ms), $t(30) = 2.83$, $p < .01$, attentional interference

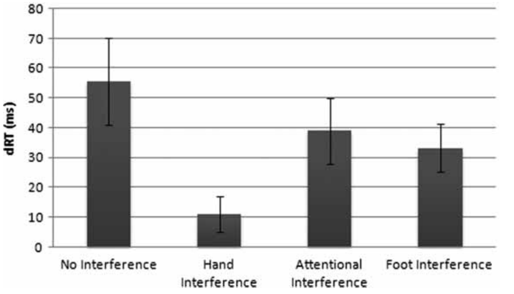

Figure 2. *Mean reaction time differences between incorrect and correct actions (dRT) as a function of the different training conditions (no interference, hand interference, attentional interference, and foot interference). Error bars indicate the standard errors.*

(39 ms), $t(30) = -2.20$, $p < .05$, and foot interference (33 ms), $t(30) = -2.28$, $p < .05$, which were not different from each other, all *p*s > .19.

Discussion

The present study aimed to examine the role of motor simulation for the acquisition of functional object knowledge and demonstrates a selective impairment of the verbal learning of object functions if it is accompanied by an execution of a manual motor action (i.e., squeezing a ball). This finding of a selective motor interference effect on object learning is in line with the idea that covert motor simulations support the acquisition of functional object knowledge.

Previous research (van Elk et al., 2008) has shown that performances in object detection tasks reflect participants' functional object knowledge by showing that objects presented at the associated action goal location are recognized faster than objects at another location (e.g., cup at eye). The calculated difference between the object detection times toward correct and incorrect action in the test phase could be consequently interpreted as an indicator for the functional object knowledge that participants acquired during the learning phase. Accordingly, participants in the no interference condition showed a substantial learning effect indicated by the facilitated detections of objects presented at its correct action goal location. Interestingly, this learning effect vanished if participants were required to perform a secondary manual motor task during the learning phase (hand interference condition). Importantly, we can exclude that the interference effect reflects a general deficit of cognitive resources or an attention effect because learning was unaffected by the oddball detection task (attentional interference condition) as well as by the foot movement task (foot interference condition). Furthermore, participants had no difficulties remembering the correct sentences in the training phase, rendering it unlikely that the secondary task impaired the verbal performance itself. Additionally, the learning effect cannot be attributed to any perceptual differences between the pictures because the analysis for the reaction times to the untrained objects did not reveal differences in the recognition time between action pictures containing correct and incorrect actions.

The results demonstrate moreover that the acquisition of manual object knowledge was selectively impaired as the consequence of the concurrent manual action but not if concurrent actions with the feet were performed. This finding suggests that covert motor simulations are effector-specific and is thus in line with neuroimaging studies showing effector-specific cortical activations while action-word reading (e.g., Hauk et al., 2004; Rueschemeyer et al., 2007). Based on this literature, one might speculate that covert simulations of hand-related motor actions were selectively impaired while ball squeezing (hand interference condition) as the result of an effector-specific activation of motor areas in the brain.

The present finding of a motor interference effect on the acquisition of functional object knowledge goes beyond previous research that claimed that object recognition relies on motor knowledge about the use of an object (Canessa et al., 2008; Chao & Martin, 2000). This claim was indirectly supported by a recent study in which participants were trained with novel objects (Kiefer et al., 2007). Participants either had to make an action pantomime towards the object displaying its use or had to point to it. Interestingly, only the pantomime group showed activations in motor areas when confronted again with the objects showing the influence of action knowledge on object processing. It is important to note that participants in our study did not acquire knowledge about the functions of novel objects through own action experiences. Despite the fact that learning occurred purely verbally and without active interactions with the object, we observed that functional object knowledge was selectively impaired by a concurrent motor task. Our study therefore suggests that motor processes also underlie the verbal acquisition of object knowledge, which is not based on own action experiences.

However, whereas it is clear that a concurrent motor task impairs the acquisition of functional object knowledge it remains unclear whether the effect of this knowledge on the perceptual task is based on a faster detection of compatible trials or on a cognitive interference in incompatible trials due to the overall reaction time differences between the four conditions. Further research involving a neutral baseline is needed to address this question and to differentiate between both possibilities.

The present results not only add to our understanding of the representation of functional object knowledge but may also have implications for an embodied theory of language processing. Studies provided evidence that language processing automatically activates effector- and modality-specific subsystems (for an overview, see Pulvermüller, 2005) and that it behaviourally interferes with perceptual and motor processes (Glenberg & Kaschak, 2002; Zwaan, Stanfield, & Yaxley, 2002) suggesting that perceptuo-motor processes contribute to the understanding of language. However, it is unclear whether the activation of motor representations is indeed necessary for language comprehension or if the activation of the motor system is merely a by-product of an amodal information processing (Fischer & Zwaan, 2008). If perceptuomotor simulations are indeed necessary for language comprehension we would expect that the verbal acquisition of novel object knowledge should be affected by a concurrent motor task. Our finding that an occupied manual motor system affects selectively the verbal acquisition of new functional object knowledge could be thus interpreted in accord with a strong embodied approach. However, future research is needed to test this speculation directly and demonstrate that our finding of an effector-specific motor interference effect on semantic processing while object learning can be generalized to other language-related processes.

In summary, the present study demonstrates that verbal acquisition of novel functional object knowledge is selectively impaired while performing a concurrent manual motor task. Our finding of an effector-specific motor interference effect on object learning provides evidence for the crucial role of the motor system in knowledge acquisition and for the claim that the processing of knowledge about functional objects consists in a covert simulation of associated motor programmes.

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